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MODELING, SIMULATION AND EMERGENCY RESPONSE

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ABSTRACT

The Department of Energy's Atmospheric Release Advisory Capability (ARAC) has been developed at the Lawrence Livermore National Laboratory to provide a national capability in emergency response to radiological accidents. For the past two years the system has been undergoing a complete redesign and upgrade in software and hardware. Communications, geophysical databases, atmospheric transport and diffusion models and experienced staff form the core of this rapid response capability. The ARAC system has been used to support DOE commitments to radiological accidents including the Three Mile Island accident, the COSMOS satellite reentries, the TITAN II missile accident and several others. This paper describes the major components of the ARAC system, presents example calculations and discusses the interactive process of the man-machine environment in an emergency response system.

INTRODUCTION

The dictionary [1] defines "emergency" as a sudden, urgent, usually unforeseen occurrence or occasion requiring immediate action. Synonymous with this is the idea of "crisis"--a vital or decisive turning point in a condition or state of affairs, and everything depends on the outcome of it. Moving from the dictionary to the more specific meaning of emergency to the Department of Energy [2] one finds "Emergency: Any significant deviation from planned or expected behavior or course of events which could endanger or adversely affect people, property, or the environment." The idea of "response" is the reply, answer and/or action of the appropriate individuals or authorities (usually, but not always, governmental).

A model is a standard or example for imitation or comparison and also is a representation, generally in miniature, to show the structure or serve as a copy of something [1]. Simulation is defined as the act or process of pretending; feigning [!]; an assumption or imitation of a particular appearance or form [1]. Though a slight bit dated in meaning, one can begin to understand how these definitions have been applied to the world of computers.

At this point it seems appropriate to pull these loosely mentioned definitions into a more cohesive idea. In today's computer vernacular, models are a numerical calculational methodology to represent some physical process(es) or system(s). Simulation is the process of using one or more model(s) to provide insight into the variable or dynamic aspects of a calculation as a function of the essential input data. Emergency response has to do with the actions taken by authorities to terminate, contain or ameliorate the conditions which have precipitated the crisis.

Under the auspices of the Department of Energy, the Lawrence Livermore National Laboratory has developed a service to provide real-time assistance to governmental authorities in the event of any radiologic accident or event which releases radionuclides into the atmosphere. This service is known as the Atmospheric Release Advisory Capability or ARAC. Over the past twelve years the ARAC has evolved from a research to an operational phase. It has responded to over 125 real-time situations, including a large number of exercises and all potentially significant actual radiological incidents since Three Mile Island. The system is currently being expanded to include additional users, the upgrading of computational facilities and increased staff. This expansion will permit continuous operation of the ARAC center in Livermore by the end of FY-1985.

ARAC

The Atmospheric Release Advisory Capability is a real-time emergency response service based on the premise that computer models and simulations can be of immediate and vital assistance to decision makers faced with the problems of a release of radioactive substances into the atmosphere. The ARAC can best be described as an integration of computer models, communications, databases, meteorological data, and experienced staff dedicated to the generation of a rapid simulation of the atmospheric transport and diffusion (and possible deposition) of the released material. The results of the simulations are made available to the supported site and decision makers early on (15-45 minutes) in the emergency response through the channels and procedures defined in the Federal Radiological Emergency Response Plan (FRERP) and the Federal Radiological Monitoring and Assistance Plan (FRMAP). All federal agencies which have responsibilities for radioactive materials are covered by these new plans, including the Department of Energy (DOE), Department of Defense (DOD), and the Nuclear Regulatory Commission (NRC). ARAC simulations or assessments are also potentially available to state and local government authorities through DOE's Regional Assistance Program (RAP) and the Accident Response Group (ARG) for a wide range of events. The Nuclear Emergency Search Team (NEST) is also supported by ARAC in its response to extortion/terrorism threats involving radiological material.

BACKGROUND

Historically, federal government responses related to radiological incidents/accidents had been dispersed and confused. The dispersed nature of responsibilities had led to widely varying capabilities which were organizationally oriented and very local in scope. As a consequence, whenever an accident had impacts beyond a "fence line" both the emergency response systems and responsibilities became confused. Several major radiological events revealed these limitations: the Chinese atmospheric weapons tests of the late 1970's, the Three Mile Island (TMI) accident (1979), the purge of Krypton-85 from TMI (1980), and the Titan II missile accident near Damascus, Arkansas (1980). Through this sequence of events the ARAC system (real-time data, model calculations and professional staff) emerged as a valuable, unifying and cohesive element for rapid emergency response. Subsequent real events (e.g., Ginna NPP, COSMOS 1402) have seen an expanded role for ARAC. A major post-accident assessment calculation was prepared for the President's Commission on Three Mile Island and numerous major multi-agency exercise calculations (NUWAX, NEST, CPX, FFE, etc.) have reflected the recognition that the ARAC system provides a unique and invaluable service to the entire radiological hazards assessment arena.

As a consequence of the above mentioned events the ARAC has been thrust into a major expansion to handle the needs of several federal agencies. In 1982 the Department of Defense requested that ARAC be expanded to support approximately 45 sites in the near term with the potential for more both in the CONUS and overseas. Likewise the Department of Energy indicated a need to add about 16 sites to the original four development sites and most recently the Nuclear Regulatory Commission has formally requested ARAC support for accidents at any of the commercial nuclear power plant sites for which it has responsibility.

EXPANSION

In order to meet these increased commitments for the DOD, DOE, and NRC, an upgrade and expansion plan was developed and mutually funded by the

DOD and DOE to arrive at a new level of preparedness and capabilities by the end of FY-1985. The goals of this expansion are:

- To provide a 24 hour/day staff highly trained in emergency response procedures;
- To support up to 100 fixed sites;
- To simultaneously manage three emergency responses;
- To respond rapidly to an accident at any "nonfixed" location;
- To provide for fixed sites a small computer system with which to interact with the ARAC center, display products, manage local meteorological data, and produce simple Gaussian calculations;
- To automate many manual data processing functions; and
- To provide complete computer backup for the center.

Operationally, ARAC has used the Lawrence Livermore National Laboratory's major computers (CDC 7600s) along with several smaller Hewlett Packard and Digital Equipment Corporation (DEC) minicomputers to complete an emergency calculation. As part of this expansion it was decided that a dual DEC VAX 11/782 system with DEC LSI 11/23 front end communication systems and DEC PC 350 site computer systems would provide the capacity and commonality to develop the expanded system. Figure (1.) provides a schematic diagram of the hardware configuration at the ARAC center.

During this year many of the components of this expanded ARAC system will be completed. For example, the additional staff for the 24 hour/day operational mode have been hired and are completing their extensive training programs. The computer hardware procurement and installation has been completed and the transition to newly developed system capabilities has begun. In companion papers (Lawver [5], Walker [6]) several of the graphics and geodatabase components of the system are described. The fixed site small computer system is currently in prototype testing. Later this year the major computational models will be updated and operationally activated on the dedicated ARAC computer system. Due to the significant difference in cycle time between the Laboratory CDC 7600s and the VAX 11/782s, considerable production code and runtime environment optimization will be required. However, benchmark calculations performed in 1982 confirmed that due to the consolidated operational environment on a single computer, the net "wall time" for product delivery will remain the same or be improved.

Another large component of the expansion of ARAC has been the extensive software development. Automation of the data acquisition, validation, communication and data-basing processes as well as easily employed graphical display programs have the greatest potential for improving the response speed. This has been a major objective of the development of this new generation of ARAC software designated the ARAC Emergency Response Operations System (AEROS). The generalized goals of the new system have been to optimize its speed of operation, make it easy to use, and yet assure the reliability and accuracy necessary for assessment of nuclear accidents.

During the initial design of AEROS, it was realized that in order for a development staff of about 25 computer scientists, meteorologists, health physicists, and engineers to progress simultaneously on several parts of the system development, a structured software development methodology had to be employed. Such a method had to insure that system requirements would be satisfied and that the software eventually implemented would be well documented and maintainable. Also, the system needed to have the flexibility to allow future changes and additions in data acquisition, modeling methodology, communications, and graphic displays. The YOURDON [3, 4] structured development methodology was selected and most of the ARAC development team was trained in the techniques of structured analysis, design and implementation. Figure (2.) provides the overall AEROS context diagram which depicts the major components of the new ARAC system. Figures (3., 4., 5.) give increasing detail and provide simple examples of the primary working tool of this methodology, i.e., the data flow diagram.

MODELS AND SIMULATION

Several computer models are available to ARAC for use in the simulation or estimation of the consequences of an atmospheric release of hazardous material, whether on a local, regional or global scale. Local (within about 10-20 km) and regional (within about 100 km) assessments are performed with the three-dimensional numerical transport and diffusion codes known as MATHEW [7] and ADPIC [8] for estimating air concentrations, integrated doses, and ground contamination from continuous or instantaneous releases from point sources. The MATHEW code uses surface, tower, and upper air wind data to develop three-dimensional, mass consistent wind fields that include the effects of topography. Using these wind fields, the ADPIC code, a three-dimensional particle-in-cell transport and diffusion code, calculates the time-dependent dispersion of inert or radioactive pollutants. The code can include the effects of stratified shear flows, calm conditions, topographic deflection, wet and dry deposition, and radioactive decay. The ADPIC code has also been adapted to simulate the fallout of particulates with given particle-size distributions, and the plume depletion of particulates and gases over various surfaces. Several validations against tracer releases at distances to 80 km show agreement within a factor of two approximately 65% of the time, and within a factor of three nearly 80% of the time [9]. In very complex terrain these percentages are somewhat less [10] but the patterns are still very representative of the dispersal.

Models also exist for fallout (KDFOC2 [11]) and long-range transport and diffusion (2BPUFF [12], PATRIC [13]). KDFOC2 and 2BPUFF are well verified models which have been associated with nuclear weapons tests. They were tested extensively from 1964 to 1970 at the Nevada Test Site. Isotopic airborne concentrations, surface air concentrations, and surface deposition patterns were within a factor of three when compared with experimental data at ranges up to thousands of kilometers. PATRIC is a coarse resolution derivative of ADPIC adapted to operate on hemispheric scale wind fields for the transport of material on the intercontinental scale. It has not yet been operationally validated at these scales.

Though it cannot be considered definitive for any given atmospheric event, "First and probably foremost, modeling should be considered a tool, along with measurements and experience when used for emergency preparedness." [14] Several key (and practical) roles for models in an emergency are:

- Source term determination;
- Provide guidance to measurement teams;
- Bracket potential consequences derived using normalized calculations;
- Consistency check on measurements (and visa versa);
- Interpolate and extrapolate measurements;
- Provide updated time integral for total dose; and
- Help determine protective action guidelines.

It was exactly these possibilities that proved so invaluable at the Three Mile Island accident, particularly with regard to providing organization to the daily surface measurements program and the real-time airborne measurements [15].

Simulation is the active part of the ARAC project, i,e,. the process of developing an assessment, be it for an emergency, exercise or scenario development, which employs the summation of elements of the project. For an ARAC assessment this means the rapid assembly of the basic meteorological data for the region surrounding the real or simulated event from both the actual site and the Air Force Global Weather Central, interpretation and quality control checking of the data, determination of key parameters such as atmospheric stability, mixing depth, boundary layer depth, etc., and spatial interpolation of the data. Clear understanding of the local terrain influences is essential and ARAC has developed both a national terrain database (Walker [16]) and pseudo three-dimensional graphics to rapidly assist this vital step in the process. Mass adjustment and particle transport and diffusion calculations follow with both vector and particle plots available to the "assessor" to aid in the visualization and quality control of the simulation. Finally, contour or isopleth graphical products are displayed over relevant local area maps for use by the supported site and appropriate officials. Figures 6.-12. depict a set of exercise calculations prepared for one of our supported sites and they illustrate many of the concepts just described.

EMERGENCY RESPONSE

One of the primary requirements of an emergency response system is that it must produce viable information for the emergency response manager in a rapid, reliable manner and be such that it is easily understood. To this end ARAC has dedicated all of its major efforts. The near term goals of the AEROS system are to produce a complete three-dimensional set of assessment products, valid for one and two hours after event start, within 45 minutes of notification and description of the accident/incident for all supported sites. ARAC also has as its goal to provide the same products for any accident site in the continental U.S. within 90 minutes. Thereafter ARAC will provide continuing support on an update basis at 45 minutes after each hour until termination of the emergency. For non-supported sites very simple geographic background maps will be digitised in real-time, while supported sites have the advantage of customised, detailed site maps. Shortly, ARAC will provide a "quick look" initial calculation within 15 minutes of notification. This will be based on several simplifying assumptions and be of a qualitative rather than quantitative nature, but it will include the full three-dimensional wind structure and afford the emergency response manager a preview of the area at risk.

The current day product delivery methodology is via high speed telecopier. However, all the components of the ARAC Site Assessment Terminal are in prototype testing at this time and shortly full color graphical plots will be available to all supported sites which have their PC 350s installed. In addition, the full capabilities of these site computer systems to communicate "questionaire" information to the ARAC center automatically, manage and display local meteorological data, enter supplemental data, produce a simple local "Gaussian" calculation, manage and display the received ARAC center model calculations, and produce hardcopy displays should substantially enhance the emergency response capabilities of the supported sites.

Training is also a key component of any emergency response system. At the present time ARAC is involved in an average of two training exercises a month with supported sites, although some are not "real time". In addition ARAC provides two training courses a year at Livermore to the newly added DOD site staffs and also has DOE site personnel in attendance. Formal military accident courses conducted elsewhere receive special scenario calculations from ARAC and periodic updates. Finally, ARAC has participated in the planning as well as the play of all major DOD, DOE, and NRC exercises of the past year.

FUTURE

The expanded ARAC system has been designed with flexibility and future growth anticipated. The computer architecture developed can be expanded to meet further computational needs, though the physical facilities would need an upgrade of basic utilities. The software system is fundamentally capable of further growth and expansion. New databases can (and should) be developed to increase the responsiveness and quality of the system. At the present time a substantial effort is being invested in the development of a continental scale geographic or base map database to match the existing topographic database. In the future comparable demographic and landuse databases will be required, particularly as chemical accidents ascend to higher levels of importance with responsible government agencies. Extensive radiological dose conversion factor databases are also in the process of development for both the external and internal dose pathways due to exposure to a very large number of radionuclides. Comparable databases need to be developed for the chemical/toxic materials hazards area. Future applications of ARAC may range from biological substance releases to volcanic eruption ash cloud transport, dispersion, and deposition. The long range goal of ARAC is to provide a national capability for emergency response to a wide range of potential accidental releases of toxic material into the atmosphere.

ACKNOWLEDGMENT

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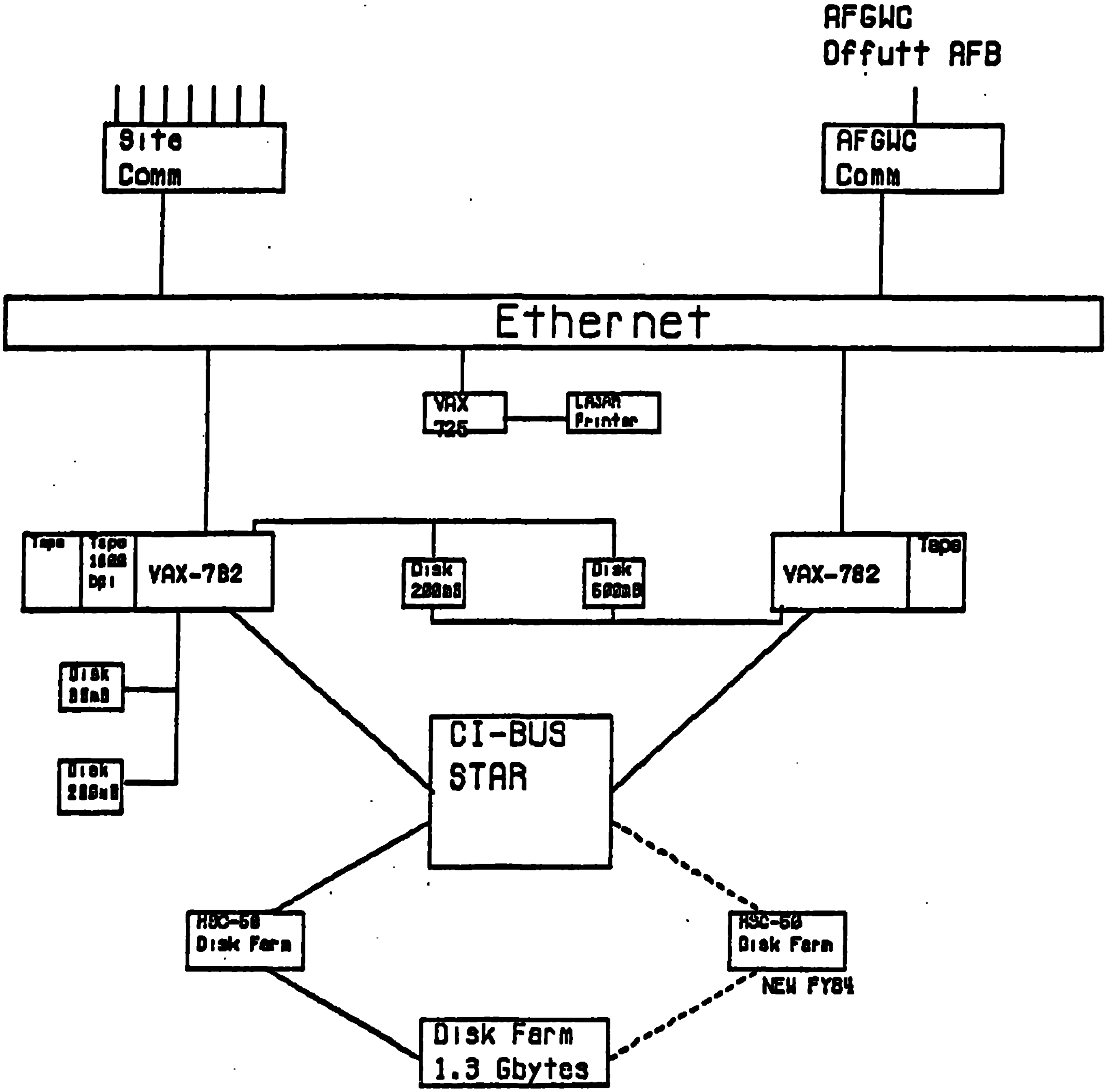


FIGURE 1. Hardware configuration of the ARAC center.

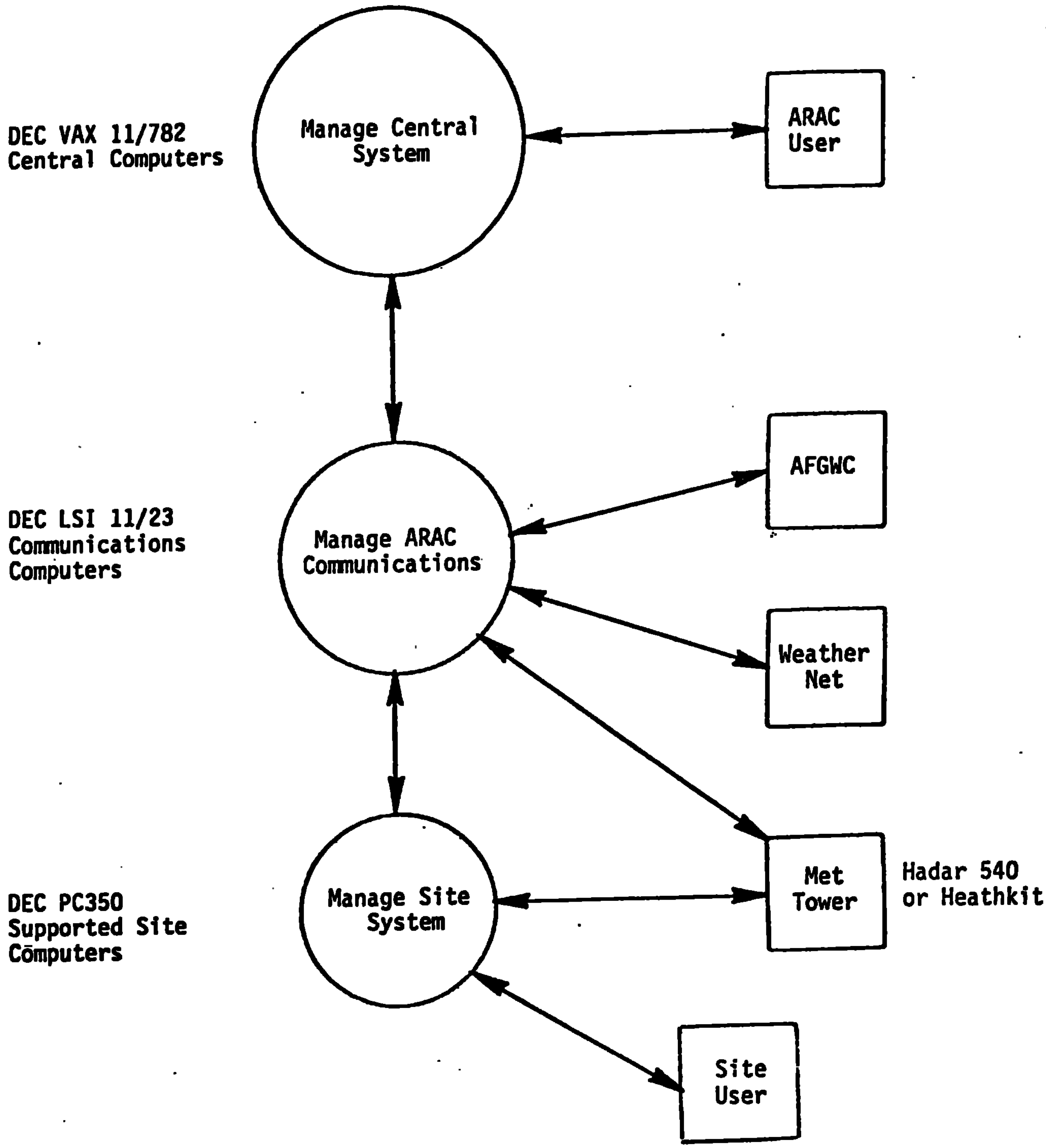


FIGURE 2. AEROS context diagram.

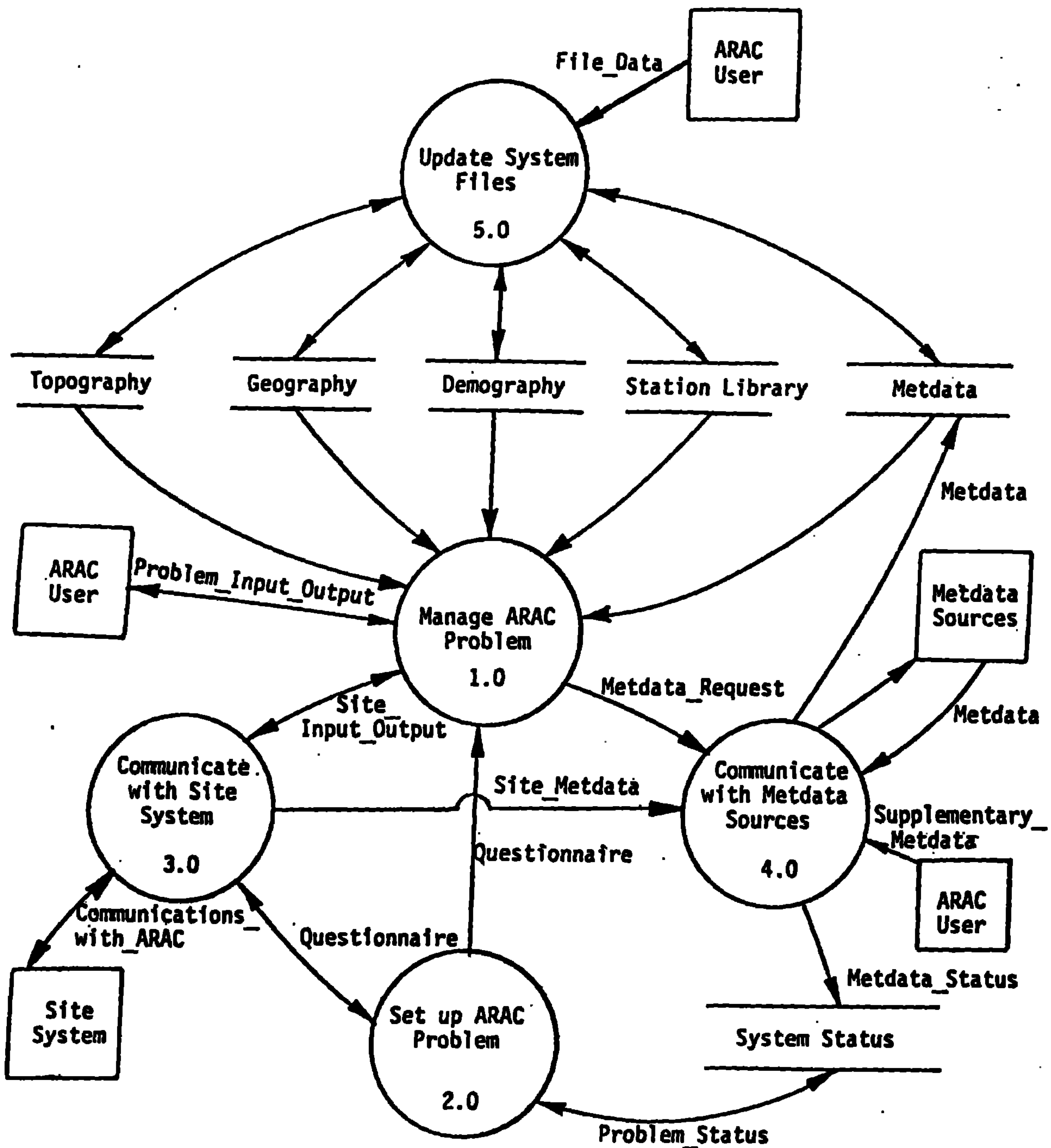


FIGURE 3. Typical Data Flow Diagram (DFD) according to the Yourdon structured development methodology. This is the top-level DFD for "manage central system."

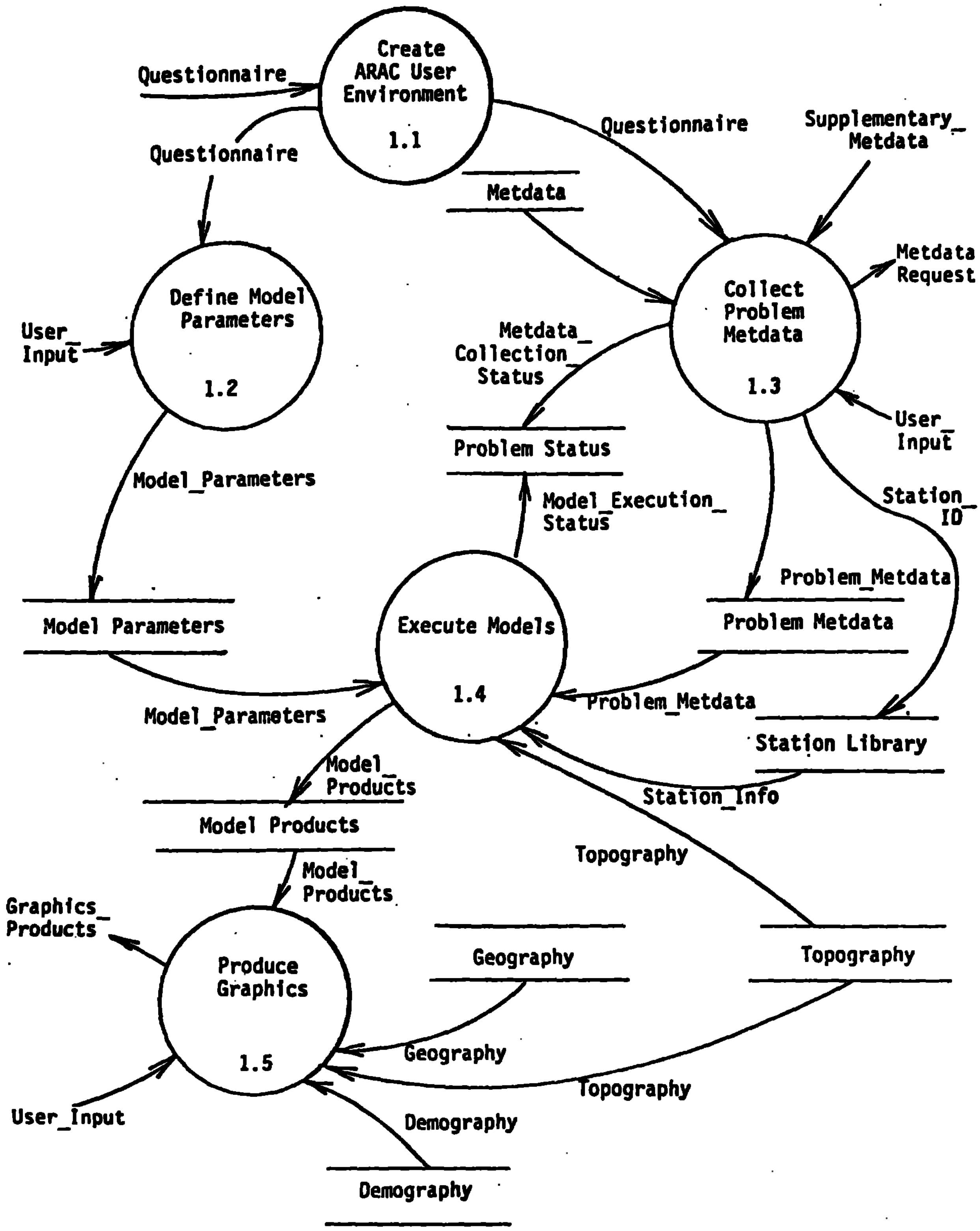


FIGURE 4. The second-level DFD for "manage ARAC problem" - process 1.0 of the previous figure.

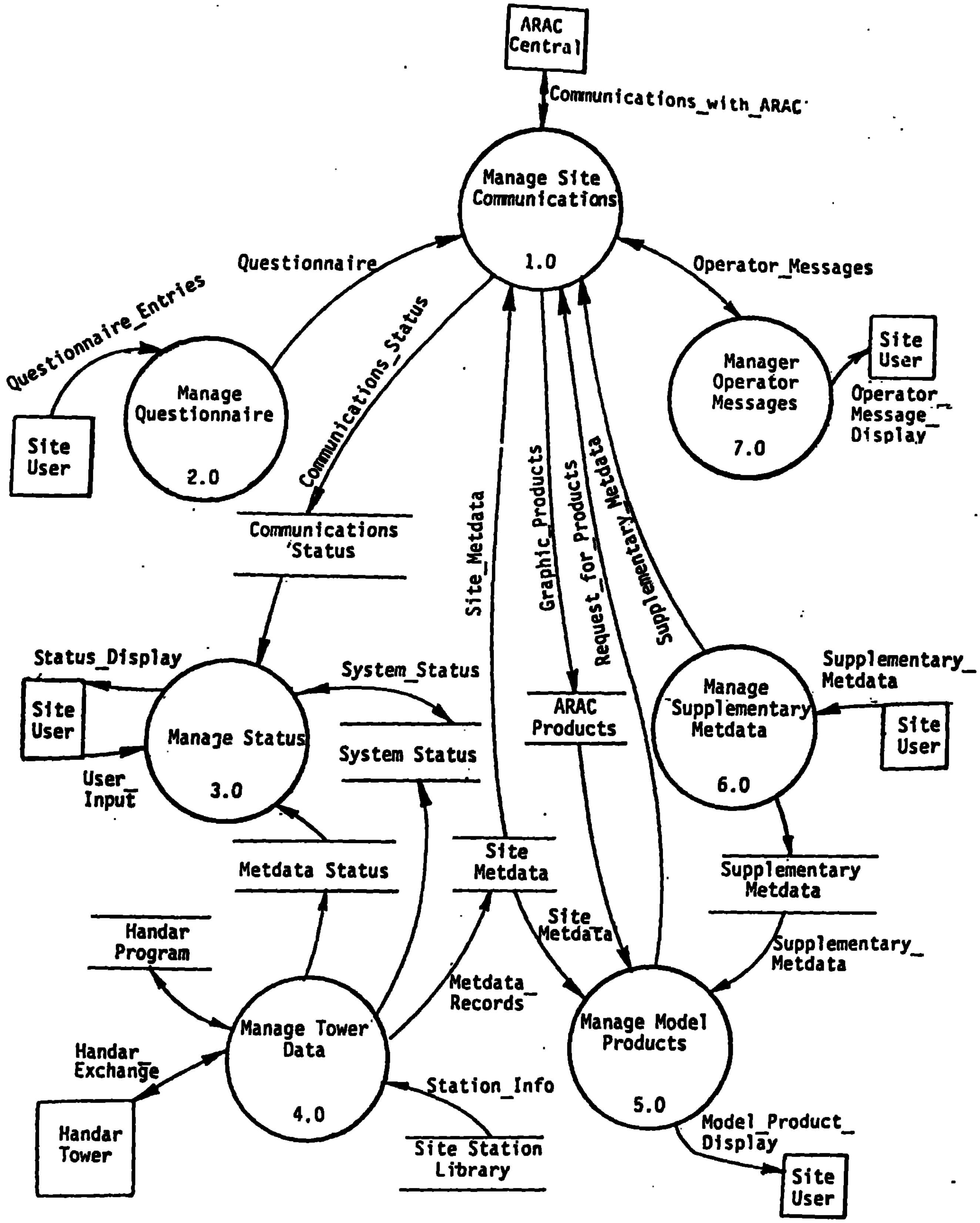


FIGURE 5. This represents the top-level DFD for the ARAC Site Assessment Terminal.

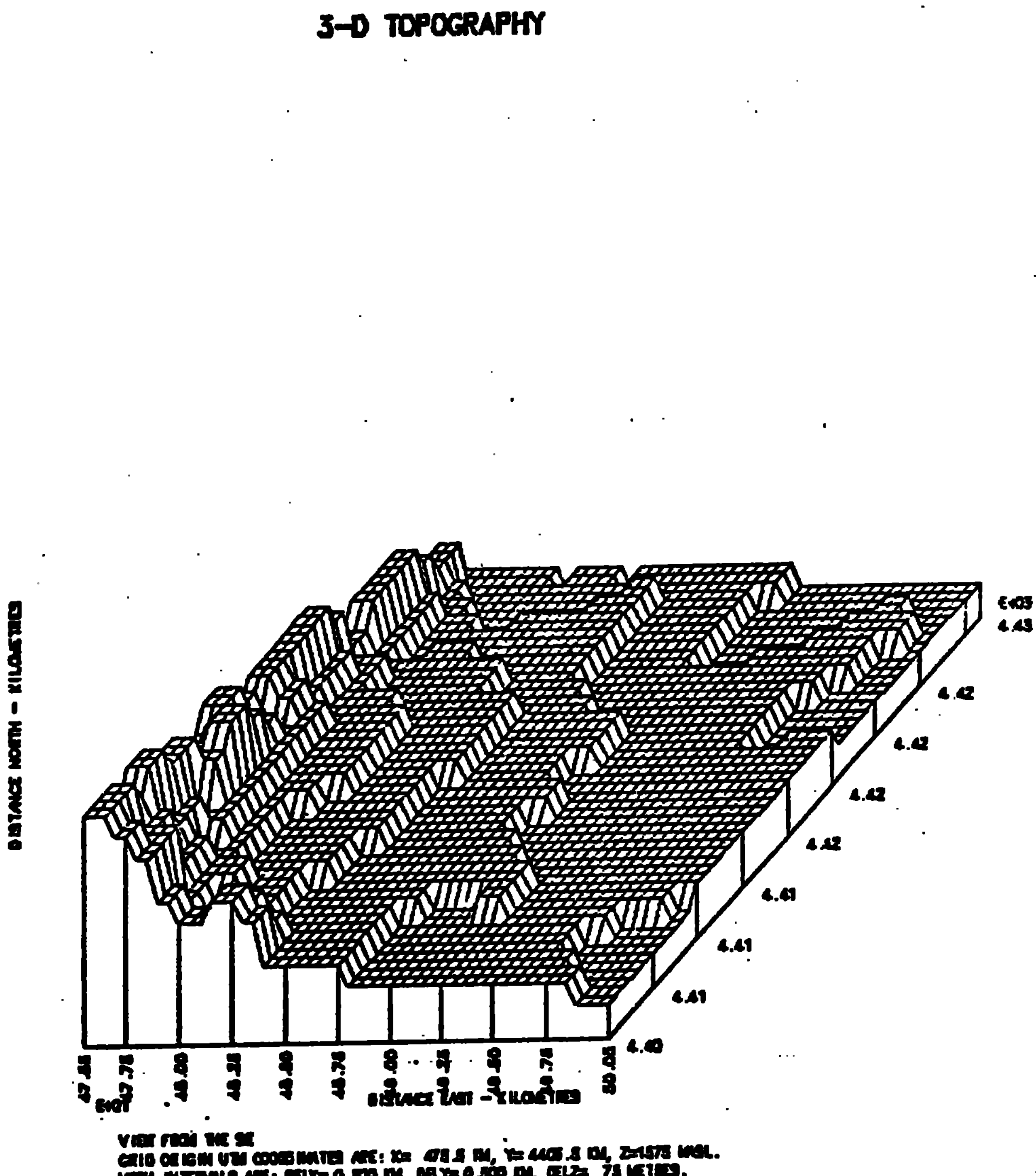


FIGURE 6. A perspective view of the model topography employed in the following exercise calculations.

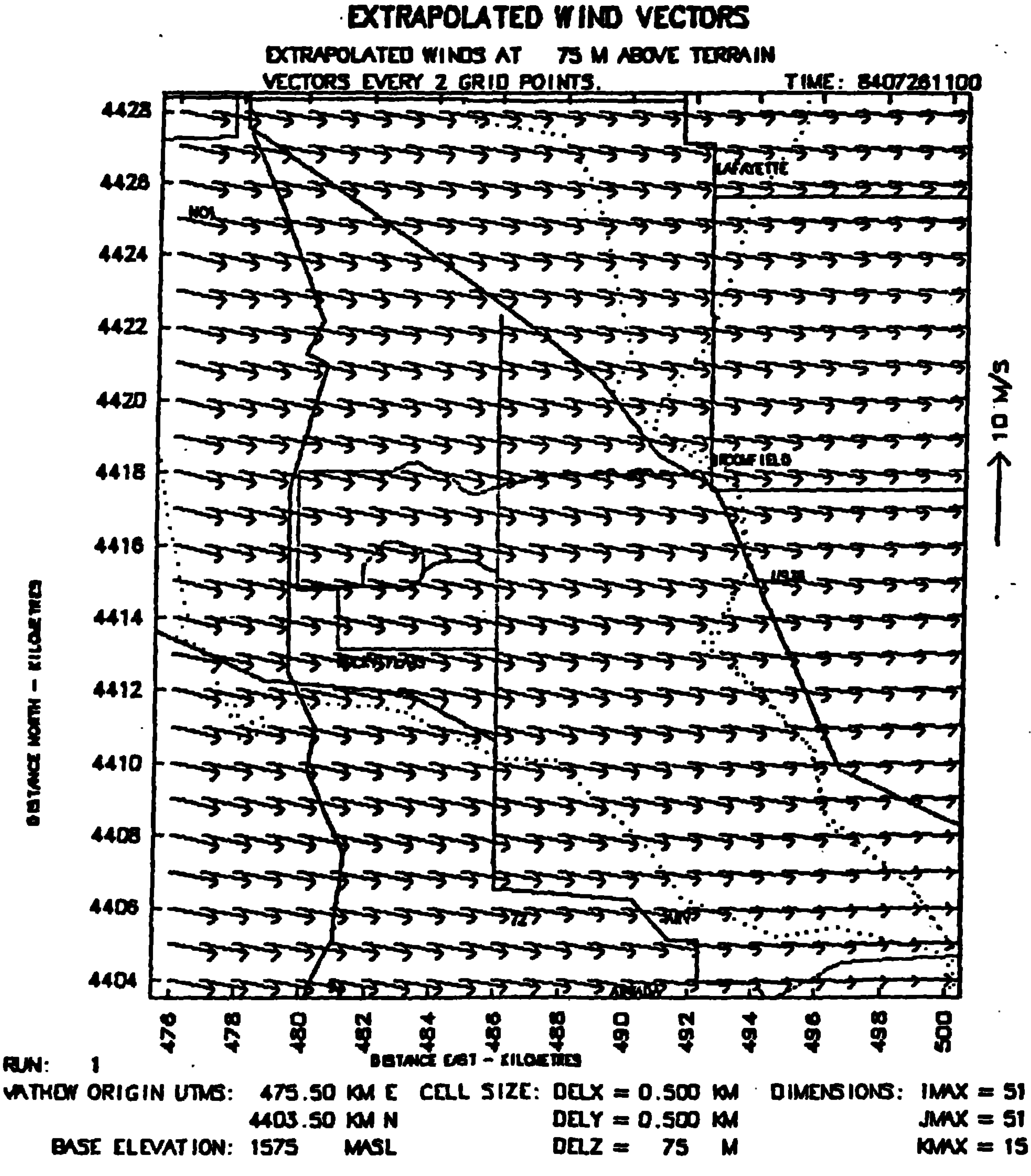


FIGURE 7. A typical example of a display of wind vectors for an initial extrapolated set of data.

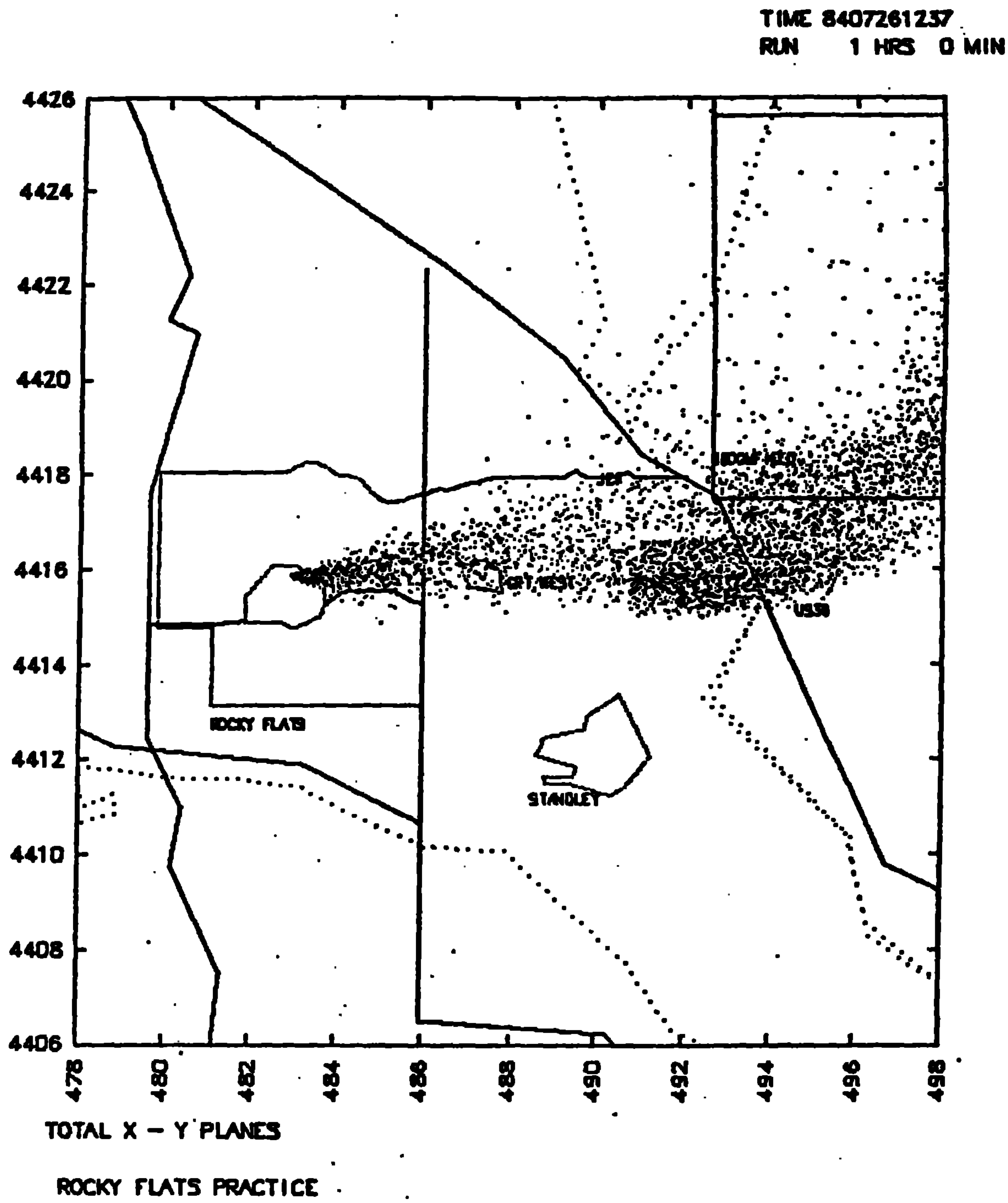


FIGURE 8. One of the direct graphical outputs from the ADPIC particle-in-cell code after one hour of continuous release.

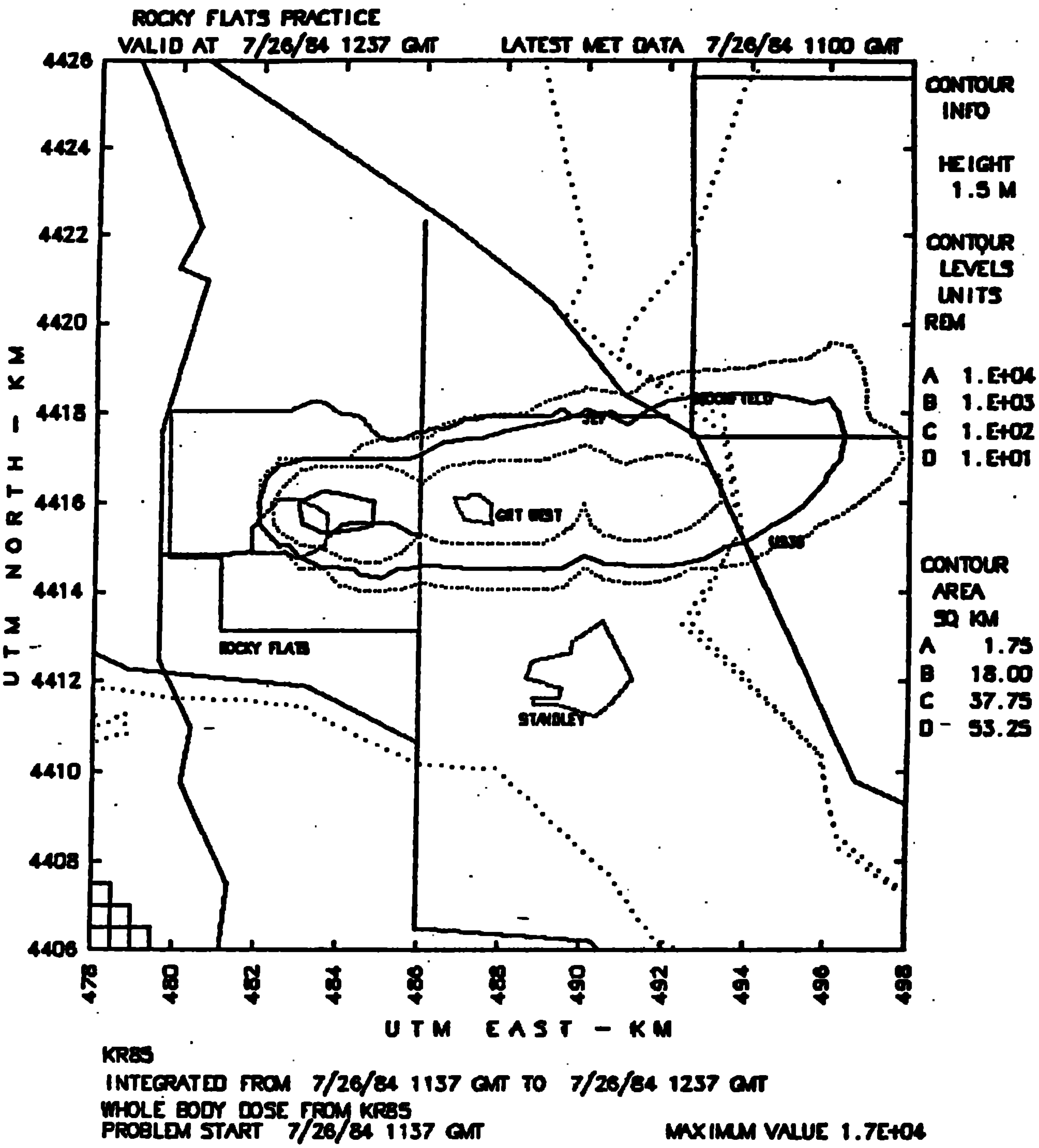


FIGURE 9. This represents the standard ARAC product with order of magnitude isopleths of whole body dose (in rem).

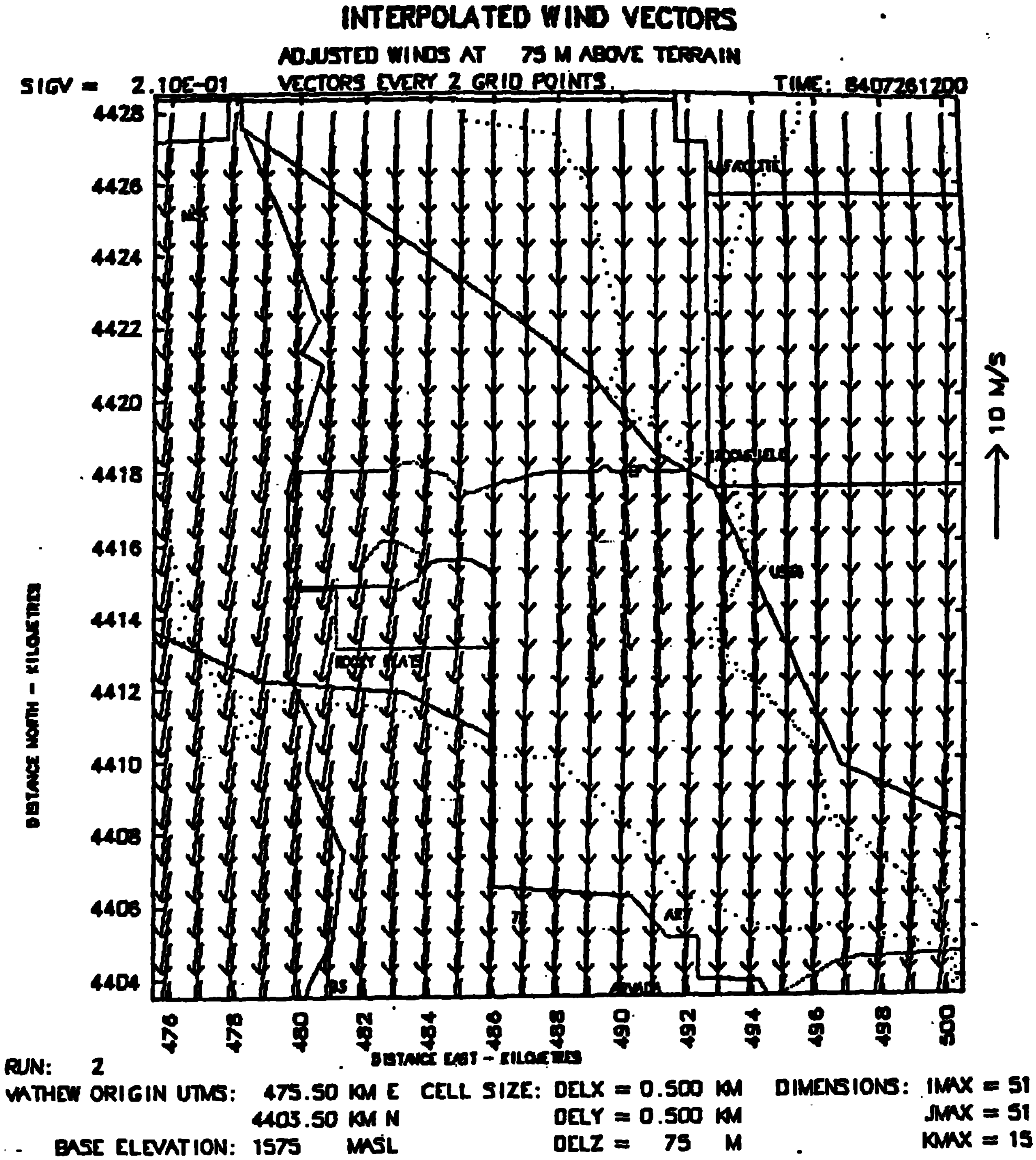


FIGURE 10. The wind vectors for the mass-adjusted flow field one hour later than FIGURE 7.

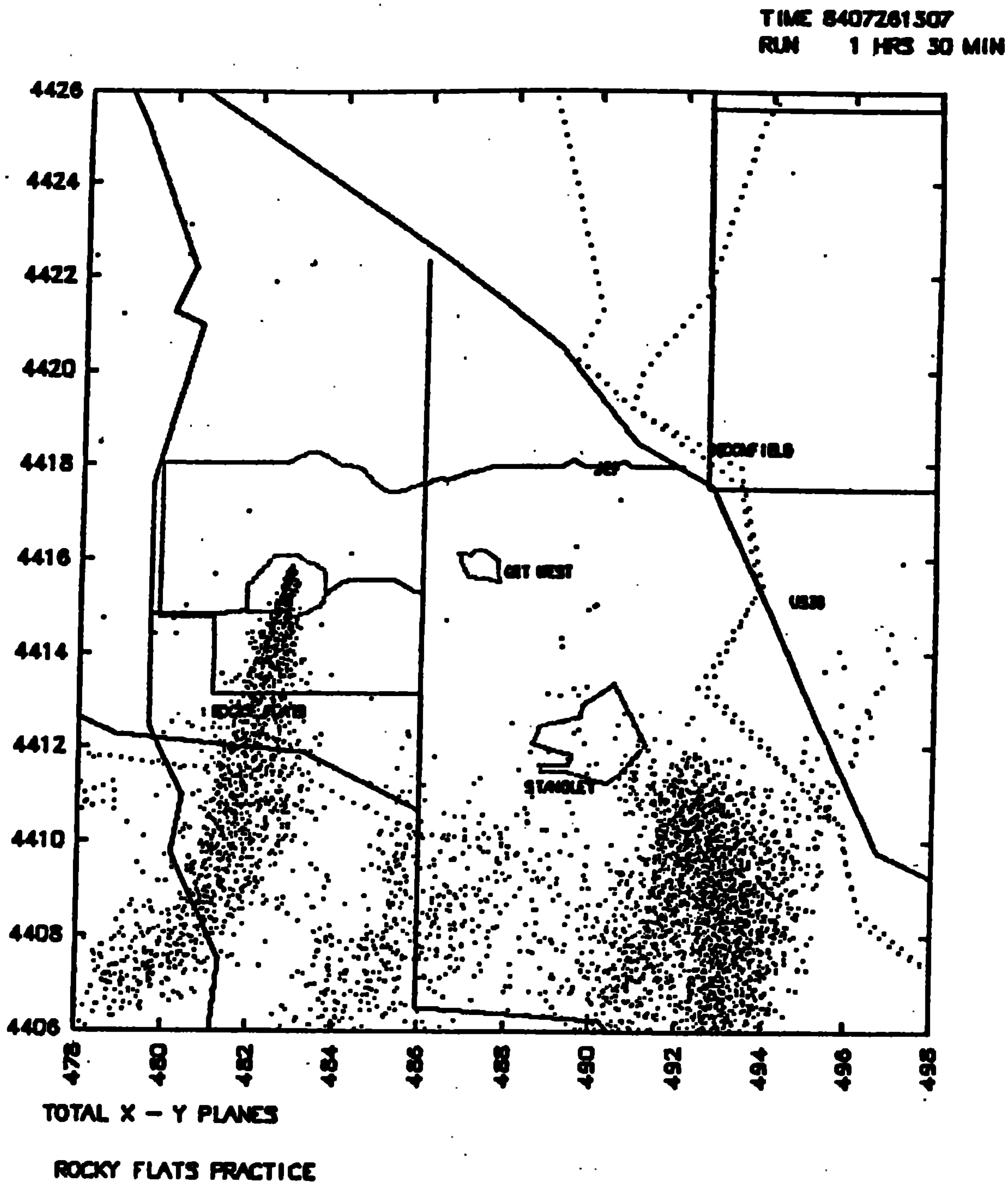


FIGURE 11. The plume of FIGURE 8. has been swept south-southwest as a result of the sudden windshift due to frontal passage.

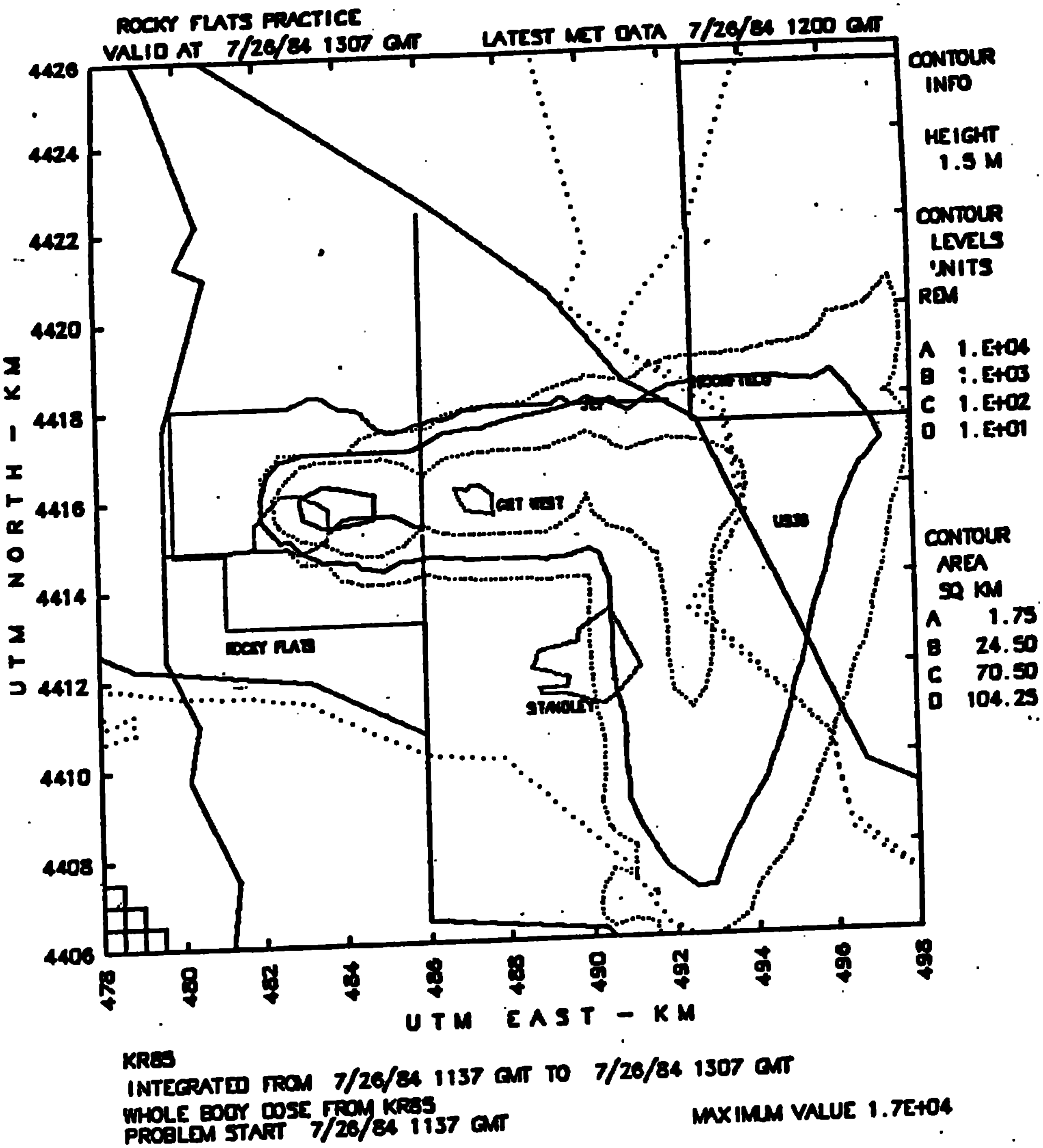
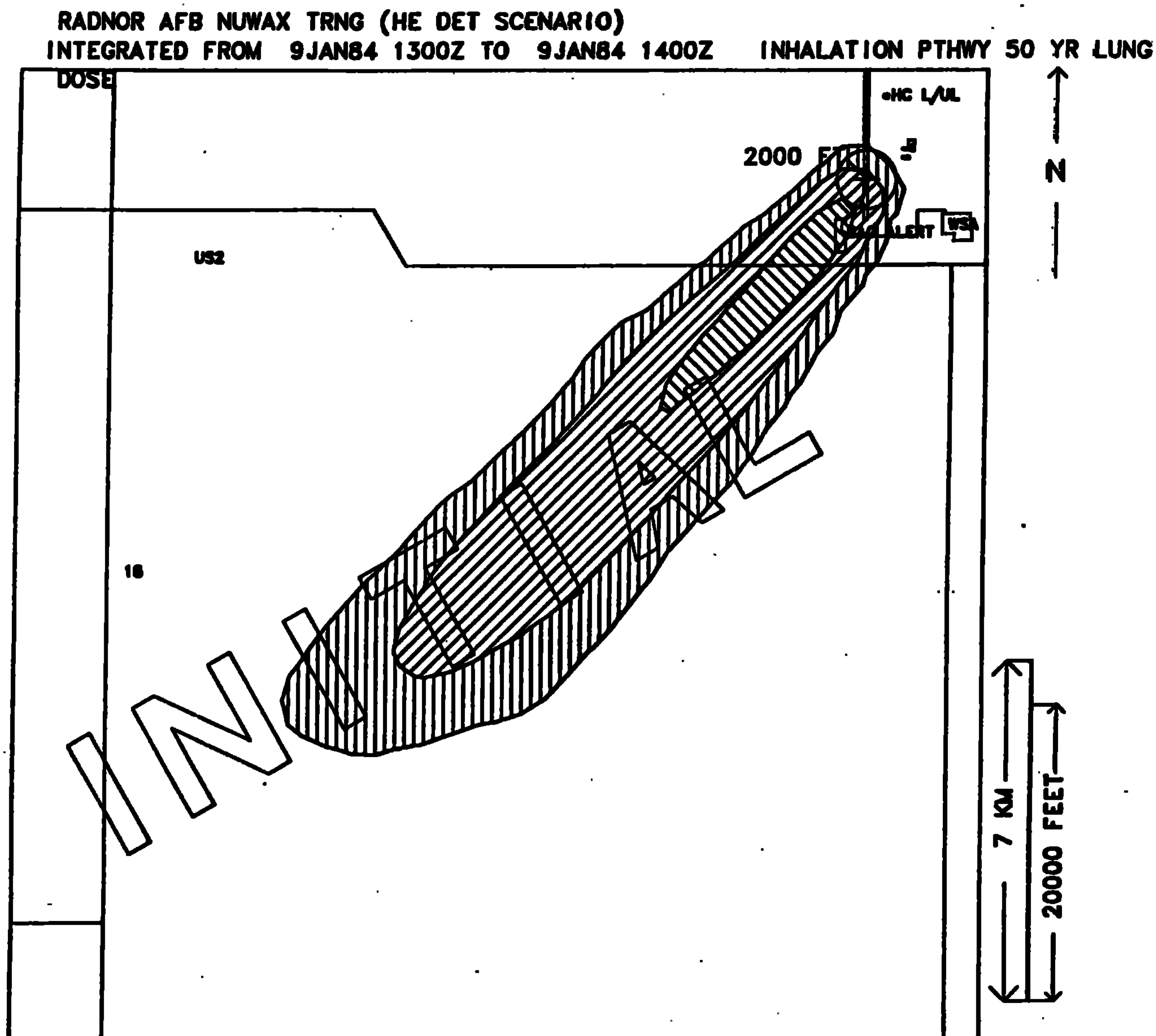


FIGURE 12. After an additional 30 minutes of calculation with the shifted winds, the dose pattern develops a distinct southerly orientation.



PU239 DOSE EXPOSURE	ACTION LEVELS	MAXIMUM: 44.37 REM
> 25 REM	PROMPT ACTION REQUIRED, RESPIRATOR PROTECTION REQUIRED, CONSIDER SHELTERING OR REMOVAL	AREA (SQ KM) 4.5
> 5 REM	RESPIRATOR PROTECTION REQUIRED, RECOMMEND SHELTERING	29.5
>0.50 REM	GENERAL PUBLIC ANNUAL DOSE LIMIT EXCEEDED	55.2

FIGURE 13. Example of a specialised plot format developed for the DOD which includes recommended action levels. The "INITIAL" indicates a quick-look calculation produced within 15 minutes of notification of an accident.

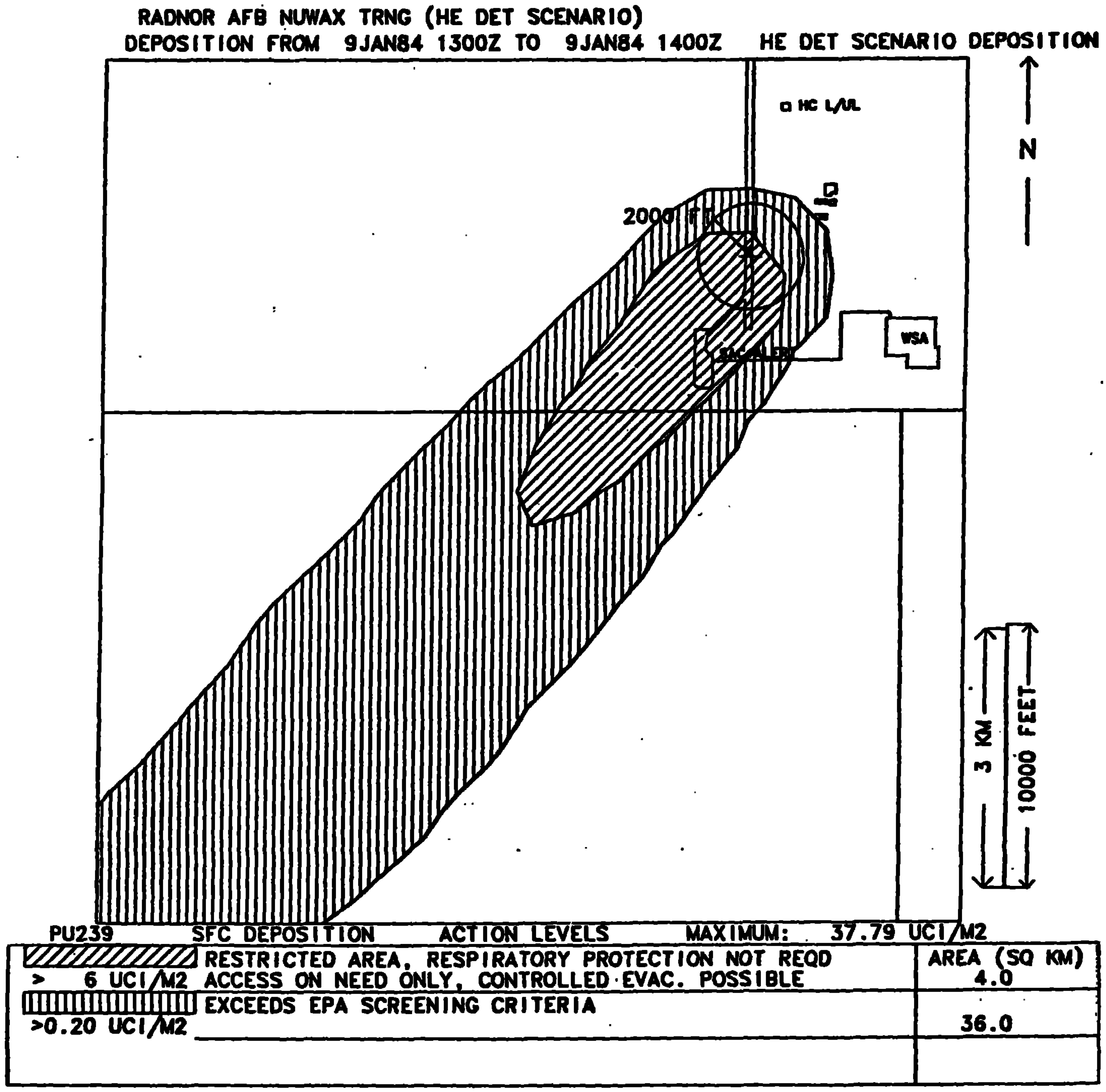


FIGURE 14. A DOD format deposition plot, similar to FIGURE 13., but based on the full response system and zoomed for greater local area detail and clarity.